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Predictive effects of the intercondylar notch morphology on anterior cruciate ligament injury in males

A magnetic resonance imaging analysis

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Abstract

The effects of the intercondylar notch morphology on predicting anterior crucaite ligament (ACL) injury in males were unknown. We aimed to determine the risk factors of the intercondylar notch on ACL injury, and evaluate the predictive effects of the morphological parameters on ACL injury in males. Sixty-one patients with ACL injury and seventy-eight patients with intact ACLs were assigned to the case group and control group respectively. The notch width (NW), bicondylar width, notch width index (NWI), notch height (NH), notch cross-sectional area (CSA), notch angle (NA) and notch shape were obtained from the magnetic resonance images of male patients. Comparisons were performed between the case and control groups. Logistic regression model and the receiver operating characteristic curve were used to assess the predictive effects of these parameters on ACL injury. The NW, NWI, NH, CSA and NA in the case group were significantly smaller than those in the control group on the coronal magnetic resonance images. The NW and NWI were significantly smaller, while no significant differences of the NH and CSA were found between the 2 groups on the axial images. There was no significant difference in the notch shape between the 2 groups. The maximum value of area under the curve calculated by combining all relevant morphological parameters was 0.966. The ACL injury in males was associated with NW, NH, NWI, CSA, and NA. These were good indicators for predicting ACL injury in males.

Abbreviations: ACL = anterior crucaite ligament, AUC = area under the curve, BW = bicondylar width, CSA = cross-sectional area, ICC = intra-class correlation coefficient, MRI = magnetic resonance imaging, NA = notch angle, NH = notch height, NW = notch width, NWI = notch width index, ROC = receiver operating characteristic.

Keywords: anterior cruciate ligament, intercondylar notch, magnetic resonance imaging, risk factor

1. Introduction

Anterior crucaite ligament (ACL) injury is the most common ligament injury of the knee joint, accounting for about 50% of knee injuries.[1] ACL injury could increase the migration of the femoral condyle relative to the tibial plateau, and led to secondary meniscus injury and articular cartilage degradation.[2] Adolescent patients with ACL injury eventually develop knee osteoarthritis.[3,4] However, even ACL reconstruction surgery could not effectively prevent the occurrence of osteoarthritis.[5]

The ACL injury was the consequence of multiple factors, such as sports type, anatomical structures, hormones, muscle, and nerve control, and so on.[6–8] Anatomical structures were 1 of the risk factors of ACL injury, including the shape of the intercondylar notch and the slope of the tibial plateau. The slope of tibial plateau was identified as a risk factor of ACL injury by biomechanical researches, but the results were controversial on imaging analysis. The ACL collided with the narrow intercondylar notch causing its injury, confirmed by arthroscopic surgery.[9] Furthermore, narrow notch have been recognized as an important factor in ACL injury on magnetic resonance imaging (MRI) in many studies.[10–14] These studies focused on the correlation between the morphological parameters of the intercondylar notch and ACL injury, but the predictive effects of these parameters on ACL injury have not been reported.

Studies reported women were more prone to suffer ACL rupture.[15–17] Several previous studies compared the parameters of intercondylar notch width (NW), notch width index (NWI) and notch shape in female ACL-injured and uninjured patients, or compared the parameters between different genders.[11,12,14] The results of these studies were inconsistent. In our department's clinical practice. There were far more men with ACL injuries than women. The main causes of injuries in these patients were sports and military training. It was important for us to guide these male

populations to avoid ACL injury. It would be meaningful to utilize these intercondylar notch parameters to identify those people at high risk for ACL injury.

In this study, we investigated the morphological parameters including NW, bicondylar width (BW), NWI, notch height (NH), notch cross-sectional area (CSA), notch angle (NA) and notch shape, obtained from the MR images of male patients. We aimed to

(1) compare those parameters between the patients with and without an ACL injury to determine the risk factors for ACL injury.
(2) evaluate the predictive effects of the morphological parameters of the intercondylar notch on ACL injury in males.

2. Material and methods

This retrospective study included male patients who suffered ACL injury due to non-contact factors, and underwent reconstruction surgery from Jan 2013 to Jan 2018. Those patients were less than 50 years old, and confirmed the diagnosis of ACL injury with arthroscopic surgery and MRI examination. They were allocated as the case group. The subjects in the control group were healthy with intact ACL and without any other ligamentous injuries or meniscus injuries. Patients with history of ACL reconstruction surgery, avulsion fractures of ACL footprint, tibiofibular, and femoral fractures, open ACL injury, hereditary musculoskeletal disorders, osteoarthritis, combined with other knee ligament injuries were excluded. The age, height, weight, and involvement of the knee joint of the patients was recorded. This study was approved by the ethics committee of our hospital (No.SAFH2018082202).

All included cases were examined using a 1.5T MR scanner (AllTech, Chengdu, China). The patient lied supine. The lower extremities were naturally straight and slightly external. The knee flexed about 10°. The coronal, sagittal, and axial scans were performed routinely, and were used to visualize the ligaments and skeletal structures of each knee. The scanning sequences included a spin echo (SE) T1 weighted image (T1WI), a gradient echo (GRE) sequence T2 weighted image (T2WI), a FSE pressure lip sequence. The thickness of each layer was 3 mm, and with a pitch of 0.5 mm. All the MR images of the knee joint were obtained and measured using the pictures archiving and communications system.

On the coronal view of MRI, a slice with the highest tibial spine was chosen. The NW_1 and BW_1 were measured using the method reported by Domzalski et al.[10] The NW_1 and BW_1 were measured at the level of the popliteal groove on the lateral condyle of the femur, parallel to the joint line formed by the distal femoral condyles. (Fig. 1 A) The NWI_1 was the ratio of NW_1 and BW_1. The NH_1 was the distance between the tangential line of the top of the intercondylar notch and the distal femoral articular surface. (Fig. 1 C) The notch CSA_1 was the inner area of the closed curve formed along the contour and the entrance of the intercondylar notch.(Fig. 1 E) The NA was formed by the two tangential line of the entrance of the medial and lateral femoral condyle through the highest point of the intercondylar notch. (Fig. 1 G) On the axial view, a slice with the deepest groove of tendon of distal lateral femoral was chosen. The NW2 and BW2 were measured using the method reported by Stein et al.[18] The NW_2 and the BW_2 were measured parallel to that line at 2/3 of the NH. (Fig. 1 B) The NWI_2 was the value of NW_1/BW_1. The NH_2

and CSA_2 on axial sequence were measured using the same way as the coronal view. (Fig. 1 D,F) The notch shape was identified using the description reported by van Eck et al.[19] A-Type is characterized by a narrow and long intercondylar notch. Its top looks like the apex of an acute triangle. U-Type is more spacious than the A-type and has a smoother top. W-Type has 2 vertices to distinguish it from A-type and U-type. (Fig. 1 H-J) In this study, the U-type and W-type were combined for analysis. Two observers were trained to measure the parameters of 30 samples independently before the study. Then they carried out the measurements without any knowledge of patients characteristics.

Data was analyzed using statistical software SPSS 13.0 (SPSS Inc, Chicago, IL). Measurement data are expressed as mean ± standard deviation ($\overline{x} \pm s$). Student t test or Chi-square test was utilized to compare the data between different groups. Binary logistic regression analysis was conducted to determine the influence of the parameters on ACL injury. The dependent variable was defined as "ACL status" (0, injured; 1, intact). The receiver operating characteristic (ROC) curve was drawn according to the probability calculated by these morphological parameters respectively. When making a multi-index combined ROC curve, the parameters that needed to be combined and analyzed were used as covariates, the ACL state was used as the dependent variable, and the combined probability was calculated using logistic regression analysis. This probability value was the result obtained by combining each included index in the multi-factor analysis equation. Then it was used as a test variable to make the ROC curve. The area under the curve (AUC) was calculated. The Youden Index was the value of sensitivity + specificity -1. The maximum value of the index was used to determine the cut-off value of the parameters. The intra-class correlation coefficient (ICC) was used to determine the inter-observer and intra-observer reliability. The ICC was 0.92 and 0.93 for inter-observer and intra-observer reliability respectively. A P-value < .05 was considered statistically significant.

3. Results

A total of 139 male patients were enrolled in the study, with an average age of 25.38 years old (16–44 years). Among them, 61 patients and 78 patients were allocated in the case group and control group respectively. There was no significant difference in the basic characteristics between the case and control groups. (Table 1) On the coronal MR images, the NW_1 and NWI_1 in the case group were significantly smaller than those in the control group ($P < .001$, $P < .001$). There was no significant difference in the BW_1 between the 2 groups ($P = .173$). The NH_1 and CSA_1 in the case group were significantly smaller than those in the control group ($P < .001$, $P < .001$). On the axial images, the NW_2 and NWI_2 in the case group were significantly smaller than those in the control group ($P = .035$, $P < .001$). The BW_2 in the case group was larger than that in the control group, and the difference was statistically significant ($P < .001$). There were no significant differences in NH_2 and CSA_2 between the case group and the control group ($P = .458$, $P = .338$). The NA was significantly smaller in the case group than that in the control group ($P = .018$). There were 30 cases of A-type and 31 cases of (U+W)-type in the case group, 46 cases of A-type and 32 cases of (U+W)-type in the control group. There was no significant difference in the notch shape between the 2 groups ($P = .173$).(Table 2).

Using binary logistic regression models, the AUC values of NWI_1, NW_1 and CSA_1 were 0.766, 0.760, and 0.757,
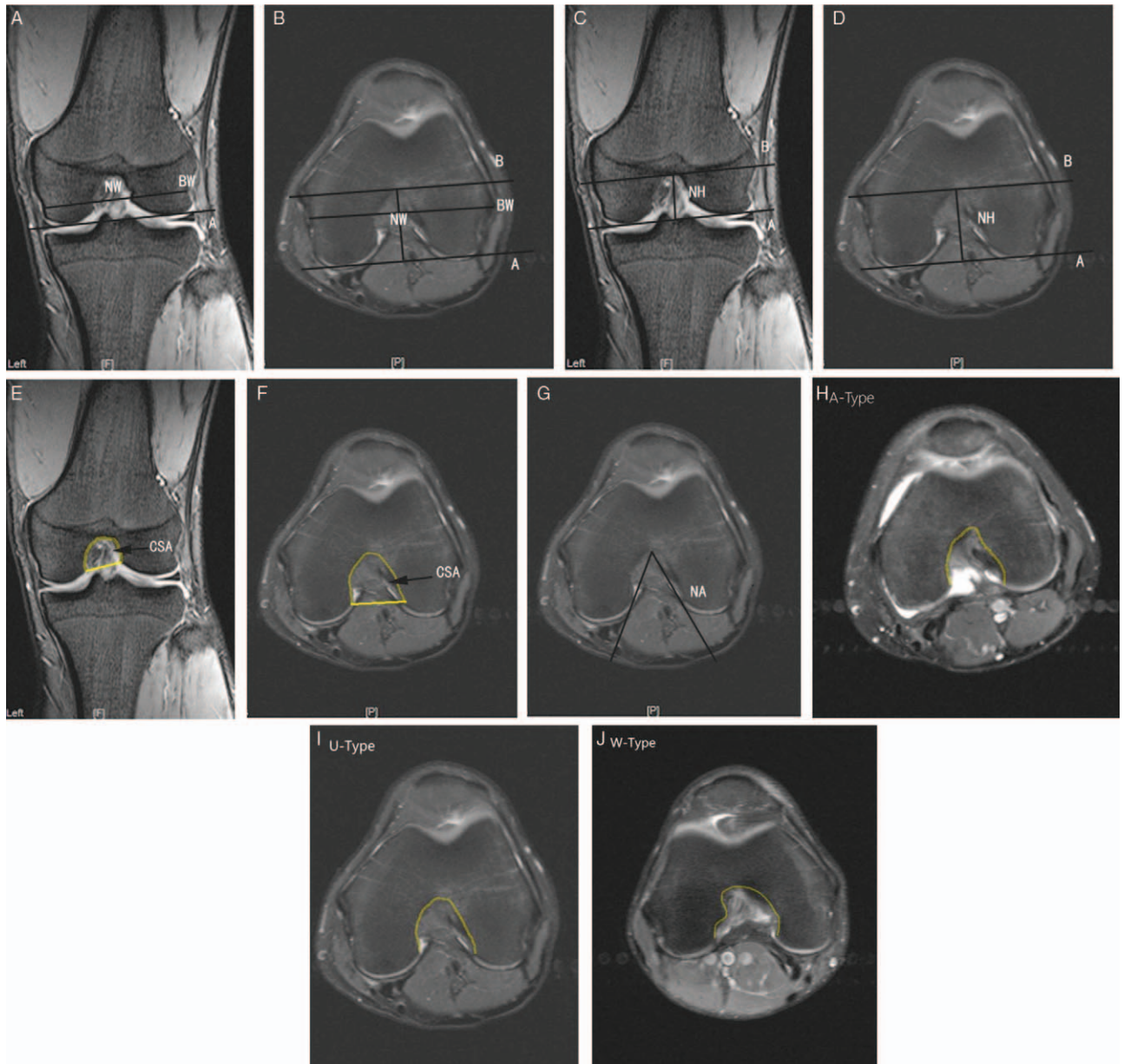
Figure 1. Measurement of morphological parameters of the intercondylar notch. A and B: The notch width (NW) and bicondylar width (BW) on coronal and axial images. C and D: the notch height (NH)on coronal and axial images. E and F: The notch cross-sectional area (CSA) on coronal and axial images. G: the notch angle. H:A-type, I:U-type; J: W-type.

respectively, higher than others. The cut-off values were 0.2809, 2.1450, and 3.0950, respectively. The AUC value, cut-off value, sensitivity and specificity of the morphological parameters associated with ACL injury were showed in Table 3. The ROC curves were drawn according to the combined probabilities

calculated from those morphological parameters, and the AUC value was calculated. Among them, the combined AUC value of NW_1, NWI_1, NW_2, BW_2, and NWI_2 could reach 0.914. When all the relevant parameters were combined, the AUC value could reach a maximum of 0.966. (Table 4, Fig. 2).

4. Discussion

The most important finding of this study was the combined morphological parameters of the intercondylar notch, which can predict ACL injury with high accuracy. We found the parameters of the notch had different effects on ACL injury. The predictive effect of each parameter on the ACL injury was low to medium accuracy. Among those parameters, the coronal NWI had the highest accuracy, followed by the coronal NW, and again the

Table 1
Basic characterize of the case and control groups.

	Case group (n=61)	Control group (n=78)	P-value
Knee (Left/right)	36/25	41/37	.494
Age, yr	26.16±5.79	24.77±4.49	.112
Weight (kg)	72.14±4.46	71.58±5.62	.524
Height (cm)	173.67±4.81	173.19±4.85	.562

Table 2

comparison of the morphology parameters between the case and control groups.

	Case group (n=61)	Control group (n=78)	P-value
NW_1	2.00±0.17	2.20±0.22	<.001[*]
BW_1	7.14±0.30	7.22±0.32	.173
NWI_1	0.28±0.02	0.30±0.03	<.001[*]
NH_1	2.37±0.22	2.60±0.34	<.001[*]
CSA_1	2.83±0.43	3.93±0.59	<.001[*]
NW_2	1.84±0.19	1.92±0.24	.035[*]
BW_2	7.78±0.39	7.48±0.40	<.001[*]
NWI_2	0.24±0.02	0.26±0.03	<.001[*]
NH_2	2.89±0.23	2.92±0.30	.458
CSA_2	3.88±0.57	3.98±0.66	.338
NA	50.36±5.70	53.75±7.67	.018[*]

BW = bicondylar width, CSA = cross-sectional area, NA = notch angle, NH = notch height, NW = notch width, NWI = notch width index.

[*] $P < 0.05$, statistically significant.

coronal notch CSA. The effect of a single factor predicting the ACL rupture was limited. When combined all relevant morphological parameters, the AUC value was increased to a maximum of 0.966. The accuracy of predicting ACL rupture had been considerably improved. This also suggested that the abnormalities of the intercondylar notch might be the most important cause of ACL injury. Measuring multiple morphological parameters of the notch was valuable to predict ACL damage.

In this study, we found that both on the axial and coronal MR images, the NW, and NWI of the male in the case group were significantly smaller than the control group, and they were risk factors of ACL injury in male patients. Most studies have confirmed that intercondylar notch stenosis was an independent factor in ACL injury, and patients with intercondylar notch stenosis had smaller NWI than healthy people.[20–23] Guermazi et al[24] proposed that only NWI was a risk factor for male ACL injury. Another study found that NW was associated with male ACL injury, while NWI was not relevant.[6] Domzalski et al[25] and van Diek et al[26] reported no significant difference in NWI between ACL-injured and non-injured patients in the male or female patients. Although the results were not completely consistent, a meta-analysis study concluded that smaller NWI or NW predicts that ACLs were more susceptible to injury.[27] Previous studies had suggested that NWI was lower than 0.269, 0.21, and 0.20 when the intercondylar notch was narrow. Nevertheless, these studies had not proposed the methods to calculate the cut-off value.[18,20,28] The Youden Index indicates the total ability of a diagnostic experiment to identify a truly affected or non-affected subject. The greater the value, the better the authenticity of the diagnostic experiment. In this study, the cut-off value was determined based on this quota. When the NWI on the axial MR image was lower than 0.2403, or the value on the coronal image was less than 0.2809, suggesting the ACL with high risk to rupture.

Another finding of this study was that on the coronal MR images, the NH and the CSA in the case group were significantly smaller than those in the control group of male patients. It suggested that NH and CSA were associated with male ACL injury. Previous study reported the ratio of the NH to the medial femoral condyle height had no significant correlation with ACL

Table 3

The AUC value and cut-off value of the morphology parameters associated with ACL injury.

	AUC	P-value	95%CI	Cut-off value	Sensitivity, specificity
NW_1	0.760	<.001[*]	0.680,0.841	2.1450	0.641,0.836
NWI_1	0.766	<.001[*]	0.685,0.846	0.2809	0.833,0.557
NH_1	0.729	<.001[*]	0.646,0.812	2.4950	0.654,0.721
CSA_1	0.757	<.001[*]	0.678,0.836	3.0950	0.705,0.705
NW_2	0.611	.025[*]	0.517,0.705	1.8750	0.628,0.623
BW_2	0.708	<.001[*]	0.622,0.794	7.7450	0.769,0.492
NWI_2	0.693	<.001[*]	0.606,0.780	0.2403	0.705,0.623
NH_2	0.538	.449	0.442,0.633	3.1650	0.231,0.902
CSA_2	0.538	.440	0.442,0.634	4.3100	0.308,0.803
NA	0.616	.018[*]	0.525,0.710	47.2950	0.795,0.344

AUC = area under the curve, BW = bicondylar width, CSA = cross-sectional area, NA = notch angle, NH = notch height, NW = notch width, NWI = notch width index.
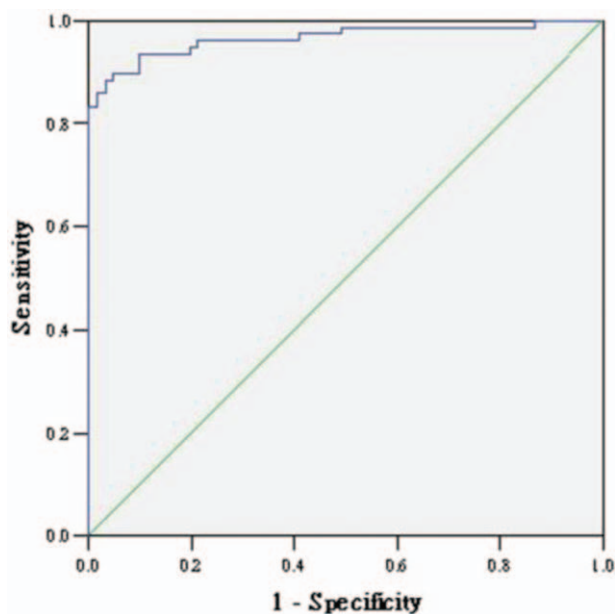
[*] $P < .05$, statistically significant.

Table 4

Combined the morphology parameters for predicting ACL injury.

	AUC	P-value	95%CI
$NW_1 + NWI_1$	0.769	<.001[*]	0.689, 0.848
$NW_2 + BW_2 + NWI_2$	0.744	<.001[*]	0.664, 0.825
$NH_1 + CSA_1$	0.760	<.001[*]	0.681, 0.838
$NW_1 + NWI_1 + NW_2 + BW_2 + NWI_2$	0.914	<.001[*]	0.866, 0.961
$NW_1 + NWI_1 + NH_1 + CSA_1 + NW_2 + BW_2 + NWI_2$	0.949	<.001[*]	0.916, 0.983
$NW_1 + NWI_1 + NH_1 + CSA_1 + NW_2 + BW_2 + NWI_2 + NA$	0.950	<.001[*]	0.918, 0.982
$NW_1 + NWI_1 + NH_1 + CSA_1 + NW_2 + BW_2 + NWI_2 + NH_2 + CSA_2 + NA$	0.966	<.001[*]	0.937, 0.995

AUC = area under the curve, BW = bicondylar width, CSA = cross-sectional area, NA = notch angle, NH = notch height, NW = notch width, NWI = notch width index.

[*] $P < .05$, statistically significant.

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